DECISION-MAKING PROBLEMS IN THE STRENGTHENING OF EXISTING AIRFIELD PAVEMENTS.

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DECISION-MAKING PROBLEMS IN THE STRENGTHENING OF EXISTING AIRFIELD PAVEMENTS

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INTRODUCTION

In the coming years there will be an increasing need to improve the airfield pavements of today. This need will not only be due to the failure of older pavements but also to the increase in the wheel loads of the modern aircraft of the future.

Many airfields in use today, especially military airfields, were rather hastily constructed during the war years without a great deal of planning for the future. However, these airfield pavements were to prove quite serviceable as long as there were no significant increases in the size of the aircraft being handled. But the day came when the operational aircraft became too heavy for the existing runways, taxiways and aprons.

Since a great deal of money is rarely available for military construction in peacetime, relatively speaking, an economical means had to be employed to improve the airfield pavements. The pavement overlay seemed to be the solution to the problem. An overlay is a variable thickness of pavement constructed on top of the existing pavement. A concrete or bituminous overlay may be applied to either a rigid or flexible pavement.

While the pavement seemed strong enough to handle the heavier loads, these loads brought out defects in the subgrade. The subgrade could no longer provide suitable support for the pavement in some cases. An unstable subgrade may be the result of the

actual physical properties of the soil, poor drainage conditions or a combination of both. To correct the situation the general procedure was to remove the existing pavement and the poor soil and fill with a selected material and reconstruct the pavement. This often proved to be quite expensive and interrupted airfield operations to an extent. A newer technique has been developed and has been used experimentally with satisfactory results. The technique involves electro-osmosis to dewater the soil and often to introduce a waterproofing chemical into the soil. The waterproofing involves coating the soil particles with a chemical so that the soil cannot absorb water, thus preventing a saturated condition.

Airfield pavement improvement also extends to such projects as lengthening a runway in order to accomodate heavier aircraft. A major factor in the design of the various airfield pavement improvements is the economic analysis of the project. Since we live in the age of an economy-minded government it seems especially important that due regard be given to economic analysis in military construction projects. The process whereby funds are requested and appropriated for a military construction project is somewhat intricate and complicated. Further, funds appropriated for one project are sometimes diverted to another thus causing the original project to be delayed or be built as the least expensive alternative for the project. Often there is no specific life associated

with a military project thus obviating the possibility of a least annual cost analysis or capital recovery considerations. A benefit cost analysis is difficult to apply since the benefit of a runway extension or overlay cannot be readily defined in monetary terms. Often such improvements are requisite in order that an airfield carry out its assigned mission.

Other factors are introduced that further complicate the problem of economic analysis in military projects. Today there is much controversy concerning the role of manned bombers and intercontinental ballistic missiles. If a decision were to be made that manned bombers were no longer to be used then many airfields would have heavy duty pavements that would be serving no useful purpose. In effect the project life would be terminated, especially if the base were inactivated. It is very difficult to plan ahead for such decisions, especially with an election every four years. A change in administration could just as easily reverse the trend. Politics enters into the problem additionally since Congress finally appropriates the funds and every two years all congressmen and one-third of the senators are up for re-election.

Getting back to economic analysis of military construction it can be deduced that there may be no simple solution to the problem since so many other considerations exist. However an investigation into the methods currently in use will be presented

using various recent projects in the state of Washington as examples.

END

I. OVERLAYS

When a determination has been made that an airfield pavement needs strengthening in order to accomodate heavier aircraft than those for which it was designed, the use of an overlay is often employed. There are several types of overlays and the design and method of construction of each will be discussed subsequently.

Prior to the construction of any overlay, a pavement condition survey is made. This is an important step in the planning of an overlay project since it will point out all defects in the existing pavement. The survey will also encompass the determination of the effectiveness of surface drainage, the possible need for subsurface drainage and the structural adequacy of areas that have been previously repaired (5).

In addition it is necessary to correct any unstable soil conditions that have been encountered in the subgrade. A soil investigation and survey is made in order to determine the soil group and subgrade class of the soil under the existing pavement. This is requisite for the preliminary design of the overlay. It is also necessary to determine the actual thickness of each layer of the existing pavement for design purposes.

Flexible and Bituminous Overlays

Flexible and bituminous overlays can be applied to existing

pavements that are either flexible or rigid. A flexible overlay consists of a high quality base course and a bituminous surface. A bituminous overlay consists entirely of bituminous concrete or a combination of bituminous concrete and bituminous penetration macadam. General criteria have been established for the design of flexible or bituminous overlays regardless of whether they are to be placed over existing rigid or flexible pavements. These criteria are (5):

1. Subbase courses will not be used in pavement overlays.
2. Nonbituminous base courses shall consist of crushed material.
3. A portion of the thickness of a bituminous overlay may consist of penetration macadam.
4. Bituminous overlays shall have a minimum thickness of three inches.
5. Bituminous overlays greater than three inches may be planned for stage construction.

In designing a flexible or bituminous overlay for a flexible pavement the first requirement is to determine the total thickness requirement for the desired wheel load. Wheel loads in design charts are given as equivalent single wheel loads. This common standard was developed in order to convert multiple gear wheel loads to equivalent single wheels loads thereby providing a convenient basis for design and evaluation of airport pavements

subjected to different loads from various types of multiple-wheel landing gears. For flexible pavement design, the depth at which each wheel of the assembly acts independently as a single wheel, bearing its share of the weight of the total gear load, is plotted on the total pavement thickness design chart. Also on this chart is plotted the depth at which all loads on the wheels of the gear interact so that the combined effect is the same as if the entire gear load was on a single wheel.

In a dual tandem gear assembly (see Fig. 2), the depth at which each of the wheels acts independently is equal to one-half the clear distance "d" between the contact areas of a pair of dual wheels. The depth at which the forces interact as though the entire load were applied through one wheel is equal to twice the center-to-center spacing "S_D" of a forward wheel and a diagonally opposite after wheel. These critical controlling depths are abscissas of two points on a line which have respectively ordinates that are: (1) the total gear load divided by the number of wheels in the assembly and (2) the total gear load. (See Fig. 1)

In Fig. 1, line AB is representative of a dual tandem gear assembly. The abscissas of "A" and "B" are d/2 and 2 S_D; the ordinates are (1) and (2) above.

These two points span a substantial portion of thicknesses on the chart and the line connecting the two points will intersect

with lines of varying subgrade classes. The intersections determine the equivalent single wheel gear loads for the various subgrade classes and the total thickness of pavement for that class. The difference between the new thickness required and the present thickness gives the unadjusted thickness of overlay. Adjustments to the overlay thickness are made relative to the condition of the existing pavement surface and the type of overlay base that is utilized. These adjustments are (5):

1. An existing dense graded plant mix bituminous surface, in good condition, may be evaluated for base course purposes, on the basis that each inch of surface is equivalent to $1^1/2$ inches of base course provided the entire overlay will consist of bituminous concrete.
2. Under all other conditions, the existing pavement will be considered, inch for inch as base course.
3. If a bituminous base, hot plant mix, is to be utilized, a thickness adjustment may be made on the basis of one inch of such base being equivalent to $1^1/2$ inches of nonbituminous base.

In the case of flexible overlays, the thickness of a nonbituminous base shall not be less than four inches unless the existing surface is broken to an extent that it can be blended with new base course material.

Flexible and Bituminous Overlays on Rigid Pavements

Rigid pavements also may be strengthened through the use of a flexible or bituminous overlay. In order to determine the required thickness of overlay, the total thickness of rigid pavement required for the new loading is determined from the basic design curves. This thickness is then modified by a factor generally called "F". "F" represents the subgrade and subbase conditions under the existing concrete.

"F" will vary from 0.80 to 1.00 as the subgrade varies from R_a to R_e. Subgrades for rigid pavements are classed R_a, R_b, R_c, R_d or R_e by the Federal Aviation Agency. One factor in the classification is the soil group. The soil group varies from E-1 to E-13. Granular soils, those possessing less than 45% silt and clay combined, are classed E-1 through E-5. The fine grained soils are classed E-6 through E-12. Soil group E-13 is reserved for muck and peat and is unsuitable for a subgrade. Additional factors in the subgrade classification are drainage and frost conditions.

As an example, a soil of group E-5 under conditions of good drainage but severe frost would be classed as R_b as a subgrade for a rigid pavement. R_a is the best subgrade class and R_e is the poorest subgrade class. Since "F" is basically a reduction factor, it follows that the better subgrades will result in a greater reduction of overlay thickness required, as shown by the following

equation for the thickness of flexible overlays (5):

$$t_f = 2.5(F_h - h_e)$$

The thickness for bituminous overlays is determined from:

$$t_b = \frac{t_f}{1.5}$$

in which:

t_f = Required thickness of flexible overlay.

F = Factor which varies with subgrade class.

h = Thickness of rigid pavement required for new design.

h_e = Thickness of existing slab.

t_b = Required thickness of bituminous overlay.

It should be noted that if a flexible overlay is used, minimum thicknesses of six inches for base course and three inches for surface course are required. A bituminous overlay shall have a minimum thickness of three inches. Thus for overlays of less than about eight inches, the bituminous overlay is recommended.

Concrete Overlays

Concrete overlays may be placed on either flexible or rigid pavements. The minimum allowable thickness of a concrete overlay is six inches, and slab lengths normally should not exceed twenty feet. All requirements concerning the use of steel in concrete overlays are the same as those used in the design of rigid pavements. Particular attention should be given to the jointing used

in the concrete overlay. The joints of the overlays should align with the joints of the rigid pavement to within one foot if possible. However, types of joints need not be matched. Thus a contraction joint in the overlay may be placed over an expansion, construction or contraction joint in the existing pavement. If the jointing pattern of the old slab is not followed, cracks may be expected to develop over the old joints.

Concrete overlay on Flexible Pavement

This method of strengthening an existing airfield pavement is seldom employed. There is no established design procedure for determining overlay thickness. Normally the existing flexible pavement is considered as a base for the overlay. The subgrade under the existing pavement is rated for class as a rigid pavement foundation. The thickness of overlay slab is then determined from a conventional rigid pavement design chart for the new load requirements.

Concrete Overlay on Rigid Pavement

The more common use of a concrete overlay is placing it on a rigid pavement. The thickness of a concrete overlay may be determined from the following formula (10):

$$h_c = \sqrt{h^{1.87} - Ch_e^2}$$

in which:

h_c = Thickness of overlay slab.

h = Thickness required of an equivalent single slab, placed directly on the subgrade with a working stress equal to that of the overlay slab.

h_e = Thickness of existing slab.

C = Coefficient depending on condition of existing pavement.

C = 1.00- existing pavement in good condition

C = 0.75- existing pavement with initial corner cracks due to loading but no progressive cracks

C = 0.35- existing pavement badly cracked or crushed.

The FAA used the above formula, which is recommended by the Portland Cement Association.

The Corps of Engineers utilizes a similar formula:

$$h_c = \sqrt[1.4]{h^{1.4} - Ch_e^{1.4}}$$

where the terms are the same as before. The Corps of Engineers formula is somewhat more conservative yielding slightly thicker overlay slabs. In either case a minimum thickness of six inches is required for the overlay slab.

Preparation of Existing Surface for Overlay

The existing pavement surface must be readied for the application of the overlay. Any defects that were noticed in the pavement condition survey will now have to be corrected. Flexible pavement failures may take the form of break-ups, surface irregularities, depressions or pot-holes.

Areas of broken flexible pavement should be removed and replaced with a suitable new pavement. If the subgrade is at fault, it should be corrected with suitable soil and each layer of the repair should be thoroughly compacted before the next layer is placed.

Surface irregularities and depressions should be leveled by rolling or by filling with an acceptable bituminous mixture. If a leveling course is required, it should be of high quality bituminous concrete. If a flexible overlay is to be employed, the leveling may be done through the use of the crushed material to be used in the base course.

If a bleeding condition is prevalent, any excess bituminous material that has accumulated on the surface should be bladed off. In some cases a light application of fine aggregate may effectively blot up the excess material, or a combination of the two methods may be employed.

Pot holes should be filled with an acceptable bituminous mixture thoroughly tamped in place. Cracks should also be filled

and thoroughly tamped being careful not to leave any excess higher than the pavement surface.

Prior to application of a bituminous overlay the existing surface should be given a tack coat. The amount of bitumen applied will vary, depending on the condition of the existing surface. Excessively dry bituminous surfaces may require the maximum amount of bitumen. The maximum amount will generally not exceed 0.20 gallons per square yard. The new pavement should extend to three inches inside either edge of the existing pavement.

When a flexible overlay is to be applied to an existing flexible pavement, the base course layer may be applied directly on to the existing surface. The base course should extend twelve inches beyond the edge of the existing pavement and here should extend to a depth of six inches below the surface of the existing base course. The surface course should match the limits of the existing pavement.

Problems with rigid pavements that should be corrected take the form of broken slabs, pumping conditions, rocking slabs and slab distortion.

Badly broken slabs that do not rock will need no special treatment since the rigid overlay design criteria covers this condition. If the broken slabs rock they may have to be broken into smaller slabs to obtain a firmer seating.

If pumping is prevalent at the slab ends or if the slabs rock with the movement of aircraft, generally a slurry of soil cement pumped under the pavement will correct this condition.

If the rigid pavement is to be overlaid with a flexible type pavement, badly broken slabs may be replaced by an equal thickness of bituminous concrete. Any unstable subgrade conditions may be corrected by excavating and replacing with a well compacted base course material.

If the rigid pavement is not to be replaced, the new base course may be applied directly to the existing surface. The base course should extend twelve inches beyond the pavement edge and to a depth of the bottom of the present slab.

If a bituminous overlay is used on a rigid pavement, the existing surface should receive a light tack coat. The overlay should extend to three inches inside either edge of the existing pavement.

If slab distortion is excessive a bituminous concrete leveling course may be employed prior to a bituminous overlay. A separation course of granular material or of a bituminous mixture may also be used.

After any repair work the existing surface should be cleaned of all dust and dirt. Any foreign material present may break the bond between the overlay and the pavement. The existing surface should be thoroughly wet down. This is especially important in hot weather when the dampening will tend to reduce the temperature

of the existing pavement, thus reducing possible slab contraction. It should also be noted that less water will be drawn from the concrete when it is placed on an existing slab than when it is placed on a soil subgrade. Thus the concrete mix should be designed for minimum water content.

II. INLAYS

Due to certain aircraft characteristics, runways may exhibit channelized traffic patterns. It has been demonstrated, especially at various military airfields, that the center 75 to 100 feet of a runway carries most of the traffic. The runways at these airfields are generally of 300-foot width. In order to strengthen such a runway an overlay may not be the best solution. The use of an inlay as a method of strengthening an existing airfield pavement has been employed with success at several military airfields.

An inlay consists of a section of pavement designed for a heavier wheel load replacing a cut out center portion of the existing pavement. The widest application of this method seems to be in the use of a rigid inlay to strengthen an existing flexible pavement. This method leaves the outer portion of the existing pavement in place since it will be capable of serving the relatively light volume of traffic it receives. It has been more economical sometimes to strengthen a pavement using an inlay, rather than overlaying the entire width of an existing pavement (18).

The thickness of the rigid inlay pavement is determined in the same manner as for a new pavement. Excavation is made to allow the required thickness of the new pavement to be properly placed. The width is excavated slightly larger than the inlay section to allow room for side forms. The subgrade should be compacted to the

III. SUBGRADE STABILIZATION

Often the cause of a pavement failure can be traced to inadequate support of the subgrade. This inadequacy may be due to an over-saturated condition in the subgrade. When such a condition exists, it must be corrected or future pavement failures can be expected. If the saturated condition is confined to a relatively small area and the pavement is badly broken up it is usually best to just remove the saturated soil and replace it with a fill material properly compacted. However, a saturated subgrade condition may exist with the pavement still in relatively good condition. Further it may be necessary to strengthen the existing pavement for heavier wheel loads.

Several methods of soil stabilization are economically feasible and have been successfully used in subgrade stabilization projects. The more conventional methods involve the use of various admixtures to the soil. These admixtures may take the form of portland cement, bituminous materials or lime. The more experimental methods involve the addition of various chemicals to the soil, the use of electrical methods to dewater the soil or a combination of these methods. A quaternary ammonium chloride has been successfully used as a waterproofing agent in soils, which prevents a saturated condition from occurring (11). Electrical methods used involve electro-osmosis and the electro-chemical hardening of clays. Electro-chemical stabili-

density requirement for a new pavement, if necessary. The edges of the rigid inlay are generally thickened for the required edge loading in order to protect the edges of both the inlay and existing pavement against loads traveling along the edge or across the juncture. When the side forms are removed, the voids are filled with lean mix portland cement concrete or a normal paving mix. New asphalt concrete is placed above these areas matching the existing wearing course. The new wearing course over these areas shall have a minimum width of ten feet.

For inlay construction at military airfields, cement stabilization has been required in the top four inches of subgrade if the soil is not free draining (18). This prevents delays due to the accumulation of water and provides a base for any equipment that must be operated in the inlay cut. The percentage of cement used generally varies between 6% and 10% by weight.

After several years of service, the inlaid pavements have proven entirely satisfactory. Undoubtedly there will be an increasing use of inlays to strengthen existing airfield pavements.

zation has been used in at least one actual project (9). In this method, the waterproofing agent is electrically induced to flow through the subgrade, thus giving the combined benefits of a chemical treatment and electrical dewatering. This method has special merit since it can be accomplished without interruption to air traffic while subgrade treatment is taking place.

The choice of method for subgrade stabilization will be determined generally, by the type of soil, local conditions, cost and availability of materials needed for treatment. Cost of the application must also be considered.

In the case of a pavement in fairly good condition but with a saturated subgrade, due consideration should be given to electro-chemical stabilization. Electro-chemical stabilization is a combination of electro-osmosis, electro-chemical hardening and chemical stabilization. There will be no need to remove good pavement, utilizing this method.

Electro-Osmotic Stabilization

Electro-osmosis is best used for the finer-grained soils in the silt and clay range. This is because the hydraulic coefficient of permeability is lower than the electro-osmotic coefficient of permeability for these soils. L. Casagrande has shown that the electro-osmotic coefficient of permeability can be taken as a constant for practically all soils (7). Although there is a slight variation, the value can be taken as 0.5×10^{-4} cm/sec for an

electrical potential gradient of 1 volt/cm.

The surface of clay materials are negatively charged, and the adsorbed water around the particles is positively charged. If the particles are in an electric field, the cations will flow toward the cathode. Thus the water will flow toward the cathode and be deposited there. This process, basically, is electro-osmosis.

Electro-chemical Hardening

If aluminum anodes are used in electro-osmosis, there is an additional beneficial result. There is an irreversible hardening of clays when the soil is subjected to this treatment. The hardening is due to insoluble aluminates being deposited in the pores of the soil. This deposition results in a cementation of soil particles. The stabilizing effect is also due to base exchange. One and two valent ions, especially sodium, are loosely held to the clay particles. These ions are replaced by hydrogen and aluminum ions. The aluminum cation is held firmly to the clay mineral and it gives the particle a lesser tendency to attract water molecules. Thus, electro-chemical hardening represents a three way strength increase in the soil due to the decrease in water, the base exchange and the deposition of aluminates in the pores. Once the soil has been treated and lost a certain amount of pore water, it will not swell again. This has been demonstrated

by submergence of samples in water for a period of several years with no increase in water content after removal (6).

Chemical Stabilization

A chemical that has been used in subgrade treatment with good results is a di-hydrogenated tallow di-methyl ammonium chloride. It is available commercially as Aliquat H 226. This chemical is a waterproofing stabilizer when thoroughly mixed with the soil. That is to say it actually imparts hydrophobic characteristics to the soil after treatment. The chemical will improve, or at least retain the shear resistance of the soil, even in the presence of saturating amounts of water. There appears to be at least a partial base exchange where some organic cations are exchanged for inorganic cations, and these organic cations are tightly held to the soil particles (11). Laboratory tests have shown that the chemical treatment produced the best results on soils of high plasticity index. The addition of the chemical reduces the plasticity index of most soils by lowering the liquid limit and increasing the plastic limit. When any chemical is added to a natural soil, a new material is formed. This new material may have entirely different chemical and physical properties than the original. Small amounts of the chemical (0.125–0.250 % of dry soil weight) worked very well, while the addition of greater quantities had only a slight effect. Aliquat H 226 is a

viscous liquid and is supplied as 75% active solution in isopropanol, a solvent. Laboratory tests indicated it is best applied as 5% active solution by weight, and the solution should be heated to 120°-140° F prior to application.

Electro-chemical Stabilization

Several years ago the main runway at Seattle-Tacoma International Airport was showing signs of distress: a cracking and a pumping condition, notably. It was suspected the subgrade had become saturated. The pavement consisted of a six inch concrete slab with a three inch bituminous overlay. It appeared that water had seeped down through cracks in the overlay and through joints in the concrete slab, thus causing the saturated condition. The subgrade has a high clay content and has an excellent modulus of subgrade reaction when dry, but becomes unsuitable when saturated. In 1961, suspicions were confirmed when a section of the pavement had to be replaced and it was found that the subgrade was saturated up to depths of five feet. It was decided to try electro-chemical stabilization on a test section of the runway 50 feet long by 150 feet in width. The area chosen was one of maximum distress.

Four foot lengths of 1^{1}/2 inch diameter aluminum pipe were placed on the west side of the test area on five foot centers and driven beneath the surface. Along the east side of the test area a continuous steel wire was placed at a depth of four feet in a wet, open-joint drain line. The drain line would facilitate moving

the water as it collected around the cathode. Aliquat H 226 solution was forced down around the pipes so that it kept them wetted at all times. The chemical was supplied as a 2% active solution dispersed in water. A direct current potential of 270 volts was supplied between the aluminum anodes and the steel cathodes.

The treatment lasted for 18 days and did not interrupt air traffic. A total of 1355 amp-hrs of current was used along with 755 gallons of solution. The results of the treatment were quite significant and are presented subsequently. The soil resistivity decreased from 29,000 ohms/cc to 27,000 ohm/cc. Air dried samples before the treatment were easily crumbled to individual particles. After, the samples were a cohesive mass appearing to be weakly cemented. Water soluble material decreased from 1250 ppm to 600 ppm. The weight of the aluminum anodes decreased from 87.2 to 85.7 pounds. It is interesting to note that the electro-chemical equivalent of one pound of aluminum is 1400 amp-hrs. A one-half inch test rod would sink about 12 inches into the soil before treatment, while afterwards it could not be forced into the soil by hand. A 45,000-pound crash truck driven over the test area produced a deflection of 0.20 inch before, and 0.10 inch after treatment. Anode temperatures were checked periodically and were found to be the same as the air temperature, thus indicating that little energy was dissipated as heat. Examinations over the years since the treatment have indicated a noted lack of subgrade absorption

of water, and a marked ability of the subgrade to support loads.

More conventional methods of subgrade stabilization involve the direct treatment of the soils with various admixtures. Not to be forgotten is the method of removing undesirable subgrade material, and replacing it with a suitable fill material. This particular method seems to have application in the case of random, shallow areas of peat or other such material having been in the subgrade, which caused the pavement to fail.

Cement-Modified Soil

A method of stabilization that has received wide application is the addition of portland cement to the soil. This treatment is applicable to both granular and fine-grained soils. Soils treated with cement are generally referred to as cement-modified soils. These are not to be confused with soil-cements, which are hardened soil-cement structural materials produced through the addition of cement to soils. Cement-modified soils are those treated to change undesirable characteristics, thus modifying the soil into one that can be satisfactorily used as a subgrade.

Granular and fine-grained soils that are treated with cement will have improved bearing values, reduced plasticity and reduced swell characteristics. Laboratory research and field experience has shown that cement-modified soils are permanently modified. The addition of 3 to 5% cement by volume appeared to cause a permanent reduction in plasticity index. The addition of 2 to 4% cement

by volume caused permanent increase in the CBR of the granular soil (24).

In fine-grained soils small conglomerate masses of new soil grains are formed by a combination of base exchange and cementing action through the addition of cement.

In practice, the cement-modified soil results in a semi-hardened mixture. This mixture has superior characteristics compared to the soil itself. However, the mixture will disintegrate into a granular mass through weathering processess. The mixture will now function as a soil with low volume-change characteristics and increased load-carrying capacity. The treated soil will not revert to a material possessing the characteristics of the original soil.

In modifying soils by the addition of cement, several procedures should be followed closely to insure good results. The soil must be pulverized, and the cement must be uniformly distributed throughout the soil. The optimum moisture must be uniformly added, and the mixture should be compacted to maximum density. This treatment will modify granular soils to the extent they are suitable for base and subbase material. Modified silt-clay soils should be used only as subgrade material.

It should be made clear at this point that the use of admixtures to treat poor soils is one solution to the problem. There may be many situations where the use of suitable soils in their place will be best. The engineer must use his judgment in deciding when it will be cheaper, quicker and easier to modify or improve a soil through the use of admixtures.

Bituminous Stabilization

Bituminous stabilization has a somewhat limited application in subgrade stabilization. It is required that the bitumen be thoroughly mixed with the soil. The soil should be pulverized and the bitumen must be in a liquid state. Bituminous stabilization of highly plastic soils is difficult because of mixing problems.

In areas where the subgrade consists of a medium to fine cohesionless sand, bituminous stabilization is effective. Construction equipment operating on the sandy subgrade may keep the surface torn up. Bituminous stabilization provides a working floor in such a subgrade material. A successful bituminous stabilization of the subgrade has been used at a southeastern military airfield (26). About two gallons per square yard of MS-2 emulsified asphalt were mixed in the top four inches of the subgrade. It was aerated for several days and then compacted with rubber-tired rollers. This particular type of stabilization has a useful purpose in such construction projects. However, bituminous stabilization to improve a subgrade is generally uneconomical, and little additional benefit can be obtained from it.

Lime Stabilization

Lime is still another admixture that has received wide application in subgrade stablization. Low amounts of lime can modify a fine-grained plastic soil by increasing its plastic limit and in most cases decreasing the liquid limit. The soil's volume change

characteristics are reduced and there is a strength increase as well (16).

When lime is added to a moist cohesive soil there are several chemical reactions that take place, affecting the physical properties of the soil. A base exchange reaction takes place whereby the strong calcium ions replace the weaker sodium ions. The stronger ions attract the soil particles together, causing a reduction in the plasticity. The chemical reaction generally takes a few days to be completed, giving cause to a curing period. When the lime-soil mixture is compacted it is usually not affected by large amount of water such as heavy rains.

A cementing action also results in lime treated soil. Apparently the calcium reacts with alumina and silica in the soil forming new compounds that tend to cement the soil particles together in a similar manner to that produced by the hydration of portland cement (16). The lime-cementing action takes place more slowly than the hydration of portland cement. Again the lime-soil mixture must be thoroughly compacted to get the cementation effect.

A third reaction involves the formation of calcium carbonate from the carbon dioxide in the air. This is basically a reverse of the lime-producing process and is not desirable because it will prevent normal strength gains. In highly industrial areas, the carbon dioxide content in the air is relatively higher, and care must be taken to prevent the reaction from occurring.

There are several variables that enter in to the problem of determining what amount of lime should be used in the treatment process. The lime-soil mixture should have good durability to weathering processes. Generally there is an increased resistance to deterioration with increased lime content. Strength increases also with increased lime content. Since the amount of lime used is a critical factor, usually a minimum of 5% lime by weight is recommended even though lesser amounts might produce desirable results, in some cases.

IV. DECISION-MAKING POLICY IN MILITARY CONSTRUCTION

Authorization Procedure

Various methods of strengthening existing airfield pavements have been discussed, but a very important step in the planning and design of these projects has not been considered. At some time prior to the construction of a project a decision must be made as towhat design will be employed. In almost every construction project there are one or more alternatives that have been studied for possible use in the project. The decision to employ a certain alternativo is generally based on economic considerations: to get the best engineered project for the least possible cost.

In military construction, engineers must be economy-minded due to limited availability of funds and the checks made on appropriations by government agencies. Further, a proposed project will have little chance of being authorized if its cost cannot be justified.

The process whereby a project is first conceived until it is finally constructed is long and involved. Word may be received at a military airfield from higher authority that it will have to support a new aircraft, still in the experimental stage. This aircraft will have considerably heavier wheel loads than the existing runways and taxiways are designed to carry. This notice will generally be received at least one to two years in advance.

In order that the airfield continue its mission, the base engineer will commence his planning of a project to improve the existing airfield pavements. The base engineer and his staff normally will not be equipped to do the preliminary design work necessary for the submission of the project for approval. Therefore an agency capable of doing preliminary design work, including cost estimates, will receive the project. This agency may be a division of the Navy's Bureau of Yards and Docks or a Corps of Engineers district. In some cases consulting firms will be utilized. At this level, the project begins to take form, and much of the decision-making is accomplished.

The design agency will compile a preliminary engineering report. This report will include the plans and specifications for the construction work. It will have detailed cost estimates on all items of the plan. Justification must be made for any unusually high cost estimates. All alternate plans for the construction of the project will also be included. It is important that these reports be as complete as possible in all details, for the reports will serve as the primary reference source for higher levels of review.

Other projects that may be a part of a long range construction plan and therefore more routine, are handled in a similar manner to those projects started by a recent directive. All projects must be studied and a preliminary engineering report completed. Congressional sub-committees reviewing construction requests will

not accept a study of a project made at the base level only. They insist higher authority review all such requests and make appropriate studies and recommendations.

Once preliminary engineering reports are completed, a priority is established for all requests being submitted. All the various Bureaus of the Navy Department will review their requests and may reject any request at this level. They may also return any requests they feel warrant further study. Similar procedures are completed by the other services.

The requests then go to the highest military authority for review. An overall priority list is established by each service, and then all requests are sent to the Department of Defense. Here all requests are again reviewed and a decision is made as to which projects will be included in the budget request. The Defense Department requests go to the Bureau of the Budget where funds are requested for military construction compatible with budget allocations. The final step is to have the construction authorized and the funds appropriated by the Congress.

This final step is normally completed as two separate acts by Congress. The first is the Military Construction Authorization Bill. This bill authorizes the various construction projects to be built. Once a project is authorized, there is a good chance of its being completed. The missing link is the money. Before any construction can begin, Congress must appropriate the necessary funds. This also is a separate bill.

In reviewing the procedure for the military construction requests, it can be seen there are many levels at which a project is reviewed. The preliminary design agency makes the initial decision as to how the project will be built based on their study of the problem. Any one of the higher reviewing authorities may give the project a negative endorsement, which is in effect a decision not to build, or to build in some other manner. Now, the next higher echelon must make a decision whether to build. If it is decided to build, which design shall be used? Thus the decision-making policy is really a chain of decisions. Initial proposals are reviewed and investigated. Projects of questionable design or those which otherwise cannot be justified are doomed to be dropped from each service's overall priority list.

Low priority projects, those planned for convenience rather than out of necessity, may be trimmed in times when appropriations are difficult to get. The Department of Defense or a congressional sub-committee may drop the projects. Even after all the projects are authorized by Congress, a delay of several years in their construction may result. Very frequently the appropriations bill provides a smaller amount of money than is necessary to complete all projects that have been authorized. This forces the services to delay construction of projects to future years when the priority of the projects may have increased. Once a project is authorized, it does not again have to be authorized in the event of a delay in

construction to a future year.

Economic Analysis

The purpose of economic analysis is to arrive at a good engineering solution to a problem. This means building the lowest cost project that will still meet the specifications for the project. A proper economic analysis will include more than just the initial cost. Factors such as estimated service life, the anticipated maintenance costs and the expected salvage value of the project should be considered. Utilizing these factors the engineer can arrive at a solution based on the least annual cost or the least total cost of the project. Interest calculations are not necessary in military airfield projects since the funds are available for an authorized project before the contract is made.

After meeting with several engineers in various government agencies and discussing economic analysis in military construction, it became evident that some felt there was no such thing. They were of the opinion that a project is designed according to a standard manual, and the lowest bid for the construction of the project is the economic analysis. Their comments generated a desire to investigate this matter in more detail.

The feelings of some engineers in government agencies regarding economic analysis may be due in part to the system. Great emphasis is placed on initial cost of projects in the military. This of course is due to the fact that Congress must appropriate

an amount of money at one time to cover the initial cost of construction. Various officials concerned with the budget of the government are happy if this military construction figure is kept to a minimum.

But the question cannot be evaded: is the lowest initial cost of a project always the lowest total cost? The answer naturally is no. Excessive maintenance costs or the possibility of reconstructing part of the project sooner than planned can easily cause the lowest initial cost to be the highest total cost. Obviously the expected maintenance cost of various alternatives of a project should be considered in project planning. Further the anticipated life of a project must be considered. If it costs twice as much to build something that will last four times longer, the plain facts are that its annual cost is less.

Some projects will have a salvage value. That is they will be worth something when it is decided the project is to be replaced. If the salvage value is of significance, it too should be considered in determining which alternative should be built.

In military construction the application of economic analysis is sometimes difficult, yet it should not be ignored as is sometimes done. For instance maintenance costs are not considered in some projects because these funds are not in the budget of the design agency. Once the project is completed, the maintenance of it will be someone else's responsibility and the funds for maintenance are included in that activity's budget. The appropriations

from Congress for maintenance are not included in the appropriations for construction. Therefore the activity maintaining the completed project will have to worry about keeping maintenance costs at a minimum. But maintenance cost records are available and the design agency could have applied this knowledge in arriving at a decision. Further, what is to prevent a higher reviewing authority from considering these facts even though a lower level has overlooked them? A better correlation of these costs could be made, but yet sometimes it is not done.

Another complication arises in the determination of project life. A runway improvement project may be designed to last for ten years. In five years a change in the mission of the facility may make the runway inadequate. Another improvement or reconstruction may then be necessary. Thus the project could have been built for a five year life at a lower initial cost. Since the project terminated at five years, the ten-year-life runway had a higher annual cost. Long range planning is utilized in military construction, but changes in the world situation, technology or the government administration can produce a change in the mission of a military facility that cannot be predicted. One government administration may have defense fully mobilized for possible war, while the next decides to cut back defense spending to the other extreme. A change such as this scuttles many a long range plan.

Other factors influence decisions concerning military construction projects. A curious philosophy exists that all funds appropriated

for construction during a fiscal year must be expended. If they are not the funds are lost in the sense that the agency responsible cannot use these funds in the following fiscal year. However, by not expending funds an actual saving results, since the government has really spent less on construction than was planned. Congressional sub-committees take a dim view of services not expending all appropriated funds. The feeling is that too much money was asked for and therefore in the future that service shall receive less money than requested without regard to reason. There are several reasons why funds may remain at the end of a fiscal year. One is that the low bid made on a contract is too high and out of proportion to government estimates. Thus a project was not built and further study of the project is being made to determine why bids were so high. Another reason is that a low priority project may have been deferred and some of the funds diverted to another project. The remainder of the funds would carry over as an excess if not utilized elsewhere. A third reason is that a new construction procedure may have reduced the cost of building a project, and the low bid was significantly lower than the government estimate which was made one to two years or more, earlier.

The result of the philosophy is that an attempt is made to expend all excess funds. This is done by deciding to build the more expensive alternatives of various projects. So rather than achieve a saving, funds are really unnecessarily expended. This

is not good engineering practice, but again appears to be a result of the system.

Several examples of recent projects in the state of Washington will be discussed in the following sections. Aspects of the projects that will be considered, insofar as information was available, will include the following:

(1) What economic analysis was made.

(2) What alternatives were investigated.

(3) How the decision to build the project was made.

McChord Air Force Base Project

In the spring of 1961, a consulting firm was contracted by the base to do an engineering evaluation of the runway and taxiway pavement (12). A 2000-foot length of the runway was showing signs of distress along with several smaller areas on the runway and taxiway. The purpose of the evaluation was to determine the load-carrying capacity of the existing pavements and to recommend procedures for the repair of distressed areas.

The evaluation showed several deficiencies in the pavement with regard to load-carrying capacity. The base supports the jet tanker aircraft which is the military version of the Boeing 707, an aircraft with heavy wheel loads. For this aircraft the pavement did not meet the design standards, due to substandard base course and somewhat low supporting strength in the subgrade. For the fighter type aircraft, the asphalt concrete pavement was considered

too thin for the existing substandard base course. The thickness varied from $3\frac{1}{2}$ to $5\frac{1}{2}$ inches, and a minimum thickness of six inches was recommended. The most severe distress was in areas of $3\frac{1}{2}$ to 4 inch thickness.

Three plans for repair or reconstruction were studied. The first involved reconstructing the entire runway and taxiway with flexible pavement. The second was to reconstruct the entire runway and taxiway with rigid pavement. The third was to repair the existing runway and taxiway by proof-rolling, routing and filling cracks, cutting and patching spalled areas and overlaying with a three inch bituminous overlay.

The decision was made on the basis of available funds vs cost of rehabilitation, future mission of the base and future wheel loads. The decision was to implement plan three. The cost of plan three was slightly over half the cost of plan one, and about one-third the cost of plan two. The economic analysis showed plan three to be acceptable, and the costs of plan one and two could not be justified.

Paine Air Force Base Project

Studies at Paine Field pointed out the need to extend the runway by about 1000 feet (2). The boundaries of the base made the extension feasible in only one direction, to the south. The Corps of Engineers, Seattle district, made preliminary design studies,

and found that a portion of the extension would be over an area of peat approximately thirty feet deep.

The Corps of Engineers decided it would be best to remove the peat, even though it would involve excavation of about 270,000 cubic yards. In addition about 1,000,000 cubic yards of fill would be required. These items alone would constitute about 75% of the total cost of the project. The amount of fill required would have been greater if the Air Force had not agreed to change the specification regarding fill side slopes. The change was from the normal 1 vertical on 10 horizontal to 1 vertical on 1 ½ horizontal. With a cost of $0.80 per cubic yard of common fill, a substantial saving was achieved by the change.

Once this problem had been solved two alternatives were proposed. One was to pave the extension with 500 feet of flexible pavement and 500 feet of rigid pavement. The other was to pave the 1000 feet with rigid pavement. The second plan was slightly more expensive than the first.

The decision to build the project was influenced by the fact that some excess funds had to be expended. Thus the second plan was chosen primarily for that reason.

Economic analysis did come into this project in that the Corps of Engineers figured removal of all the peat was the best solution. Removal of only a part, say to a depth of ten feet, might have caused settlement problems that later would be difficult to solve. It was questionable as to how many aircraft passes would cause intolerable

settlement, and how often aircraft would actually be over the region of peat, but the decision was made to remove all the peat. The decision held and the project was approved with that specification.

Fairchild Air Force Base Project

Fairchild is a heavy bomber base in eastern Washington. The large aircraft tended to use only the center portions of the runways. After a period, the channelized traffic had deleterious effects on the pavement. The center 75 to 100 foot section of the runway was becoming distressed.

The Corps of Engineers, Seattle district, investigated the problem. The runway was a 200 foot wide flexible pavement. Two basic solutions to the problem evolved from the studies. One was to overlay the runway with a bituminous pavement. The other was to remove the distressed center section of the runway, and reconstruct it using a portland cement concrete pavement. The outer portion of the runway would remain intact. Considering future channelized traffic by the heavy wheel loads, the Corps of Engineers decided to use the inlay or "keel" as it is locally referred to. Although initial costs would be higher, it was felt the best economic solution was the inlay, since future maintenance costs could become excessive.

Once the inlay was decided upon the possibility of using

reinforced concrete pavement as an alternative was submitted. Higher authority decided the added cost of reinforced concrete pavement could not be justified, and the inlay was constructed of plain concrete pavement.

The previous three examples represent Air Force construction projects of differing nature. The design agency was a civilian consulting firm in the first example, a government agency in the others. One feature was lacking in each of the projects, though. A project life was not determined in any of the cases. The design used was made according to the Air Force specifications and would have a substantial life with proper maintenance. However, no one could say how long each improvement was designed to last.

Seattle-Tacoma International Airport Project

Sea-Tac Airport has had two major runway improvement projects in recent years. The first project was described in detail in an earlier section. It was the unique electro-chemical stabilization of the subgrade.

The more recent project consisted of an eight inch bituminous overlay. This overlay was placed over the original six inch concrete pavement which had been previously overlaid with a three inch bituminous overlay. Runway extensions at both ends of the original pavement were not in need of the new overlay, so the overlay was tapered at allowable grade limits onto the runway extensions.

Due to the thickness of the overlay, it was constructed in stages. The first stage was a binder course of low asphalt content paving mix. Two courses of high quality asphaltic concrete were placed on the binder course.

An alternate plan consisted of constructing a parallel runway to the existing main runway. Prior to 1961, this plan was not feasible since the FAA required a 3000 foot separation distance between parallel instrument runways (1). In 1961 the FAA advised they would consider a plan involving a parallel non-instrument runway at 700 feet eligible for construction with federal funds. The parallel runway could be used for instrument operation in conjunction with the main runway, but not simultaneously with it. However, the Port of Seattle estimated a new runway would involve a three year construction program, and it was doubtful that the existing runway could be maintained adequately for that period.

The FAA approved the plans for the construction of the overlay. It was completed in the summer of 1963 with a minimum interruption of service at the airport. Flights were diverted to Boeing Field during the necessary shut-down period. FAA design standards were used for the construction of the overlay, since the FAA assumed 51% of the cost of the project.

U.S. Navy Procedure

Since no airfield construction projects were completed

recently by the Navy, no example will be presented. However, procedures that would be applied to a project were investigated and will be discussed.

The Navy makes use of project analysis in its planning and design. Project analysis is, in effect, economic analysis of a project. Project analysis must demonstrate that the proposed project is the best engineered solution that will fulfill the requirements of serviceability and economy. A rather elaborate project analysis is required for the replacement of structures. This particular analysis includes an economic analysis of military property. It also covers replacement cost and future value of maintenance and operation costs. Future periodic repair items and salvage value are also included in the analysis. This procedure represents a thorough economic analysis of a construction project.

However in other areas the economic analysis is not clear and is usually left to the good engineering judgment of the design agency. Project analysis must be applied though, and in many cases this will represent an adequate economic analysis. However, there have been projects where the initial cost received considerable emphasis due to the limited availability of funds.

V. SUMMARY AND CONCLUSIONS

Summary

Various methods of improving existing airfield pavements have been presented in Chapter 1. These methods include overlays, inlays and subgrade stabilization.

Practically no use is made of the rigid overlay on an existing flexible pavement. The rigid overlay is more commonly used on rigid pavements. However in the area that was investigated, the state of Washington, no improvements utilizing the rigid overlay could be found. The flexible overlay with untreated base course is not as widely used as the completely bituminous overlay. The bituminous overlay seems to be the most widely used overlay and several examples have been cited. The bituminous overlay has been used on both flexible and rigid pavements. The bituminous overlay has also been used on rigid pavements that have been previously overlain with asphaltic concrete. Thus it appears that the bituminous overlay is the most versatile and has received the widest application.

The inlay has been used in the state of Washington and in other parts of the country. Its use will probably be limited to runways of 200-and 300-foot width, which are common at Air Force heavy bomber bases (3). The use of a rigid inlay to improve an existing flexible pavement has received the greatest use. Since this type of improvement has been successful, there should be application.

Subgrade stabilization is an extremely broad field, and only the most commonly used methods have been presented along with experimental methods that show promise. With more research and development, the use of chemical stabilizers will become more widely accepted. Such techniques as electro-chemical stabilization which successfully passed its first test, will also continue to develop and receive further application.

The decision-making policy in military construction has been shown to be a chain of decisions following the chain of command in the military. The ultimate decision on a project is made at congressional sub-committee hearings. The committee may be influenced by the geographical location of the intended construction. Members naturally desire to strive for approval of projects located in their home states or districts. The Appropriations Bill may not provide sufficient funds for all authorized projects thereby forcing the services to cut back intended construction projects.

Another factor that may influence the sub-committee is the preparedness of the men representing the services at the hearings. If a service representative is well versed on all his project requests and is able to sell the committee on his projects, the service he is representing may receive favorable action on a greater percentage of their construction requests.

Economic analysis is not always easily applied in military construction projects. Unusual specifications necessary for a particular mission may result in high costs and no possibility for

project alternatives. Economic studies are made, but other difficulties can arise. Project life is not always determined as it should be. However, changes is policy or mission may unexpectedly shorten the life of a well constructed project. Future maintenance costs should receive consideration in project planning.

The use of standard methods of economic analysis such as benefit-cost ratio or rate of return is not always feasible. The costs of a project over its intended life could be estimated with reasonable accuracy, but the benefits associated with it may be more difficult to assess. Military defense is one area in which benefits usually cannot be measured in monetary terms. Thus if the benefits cannot be defined, the benefit-cost ratio analysis cannot be applied. For similar reasons an analysis by rate of return could not be made.

Conclusions

In deciding which technique shall be employed in the strengthening of an existing airfield pavements, the engineer must evaluate many factors. There is no one universal solution. He should be aware of any unusual local conditions that might affect the design. He should be thoroughly familiar with the condition of the existing pavement, including the subgrade. The proposed construction should represent the best engineering solution to the problem. Good judgment is a primary requisite for the successful engineer.

The decision-making policy in military construction is well established and does not change radically. Naturally there is usually some room for improvement, and changes are made when it is in the best interests. The present Secretary of Defense has re-emphasized the need for economy in the military. Wasteful practices are only a burden to the government. Since military construction represents a significant part of the defense budget, procedures should be as efficient as possible.

It is felt that there are certain weaknesses in military construction procedures. There may be a possibility of removing some of these weaknesses, while others may be inherent to the system.

A better system of economic analysis could be developed for military projects. While the scope of this investigation has been limited to airfield projects, some of the conclusions may be applicable to other areas as well. The possibility of using an analysis such as least annual cost should be investigated.

In such a method, benefits are not considered, and thus the analysis could be used in defense projects. The least annual cost analysis would consider initial cost, maintenance, periodic repair items, operation and salvage value. Since these cost estimates are for different time periods during the life of a project, interest or rate-of-return calculations should be used. An interest rate of 3 to 4 % is recommended, since this is the approximate range of most government savings bonds. A specific project life would

have to be stipulated for a least annual cost analysis.

The initial cost of the project would be converted into an annual cost through the use of a capital recovery factor. This represents an annual payment over the life of the project at the specified rate of interest. All other costs could also be transformed into an annual cost through the use of interest calculations. This would be true regardless of whether the costs were at one time in the future or periodically in the future. The salvage value could be converted into an annual saving and be deducted from the total annual cost. The resultant figure would give a true account of the annual cost. Comparison of these costs among the several alternatives would give the least annual cost, and thereby indicate the method of construction for the proposed project.

The proposed method would be similar to a benefit-cost ratio analysis if some arbitrary value of benefits were given to a project. Since the benefits would now be the same for each alternative, the resultant analysis would amount to a least annual cost analysis.

A least total cost of the project could also be accomplished. This would amount to transforming all future costs to a present worth. The initial cost would of course be its present worth. The present worth of the salvage value could be obtained and again the resultant figure would represent the least total cost by present worth analysis.

There seems to be some duplication of effort in the several

levels of review in the chain of decision-making. It is also time consuming. It would seem that after the preliminary engineering report is complete and the local command has reviewed it, the report could be sent to one Navy Department board of review. This board could be comprised of representatives from the several bureaus. The Chief of Naval Operations could make his recommendations based on the findings of this board. The other services could establish a similar procedure.

A better operating efficiency seems to be achieved by the Navy since they do their own preliminary engineering reports. The Bureau of Yards and Docks will do this work for all the bureaus of the Navy. The Air Force utilizes the Army's Corps of Engineers for its preliminary design work. Two organizations on one project results in a somewhat reduced efficiency. Duplication of effort also results since many of the Corps of Engineers instructions must reflect Air Force specifications, which are already listed in Air Force instructions. A further complication results in some areas since the Air Force base engineers doing liaison work with the Army Corps of Engineers are reserve Naval Officers. Perhaps unification of the services may be the answer here.

One other area that should receive some attention is the practice of expending of all appropriated funds. This procedure is not in keeping with good economic practices. It is felt that a justification can be made in many cases for funds not being expended. It is not a matter of asking for too much or doing poor estimating.

Funds can remain at the end of the fiscal year as previously explained, and these funds should be re-appropriated if necessary. It is a very unsatisfactory procedure to reduce appropriations because a service did not expend all their previous funds.

Naturally there can be no sweeping changes made. Changes take time and testing to see if the results warrant the change. However, thought should always be given to improving present procedures. Acceptance of a procedure that needs improvement is not progress. It is hoped that the results of this investigation may contribute in some small way to the improvement of the existing procedures.

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APPENDIX A.

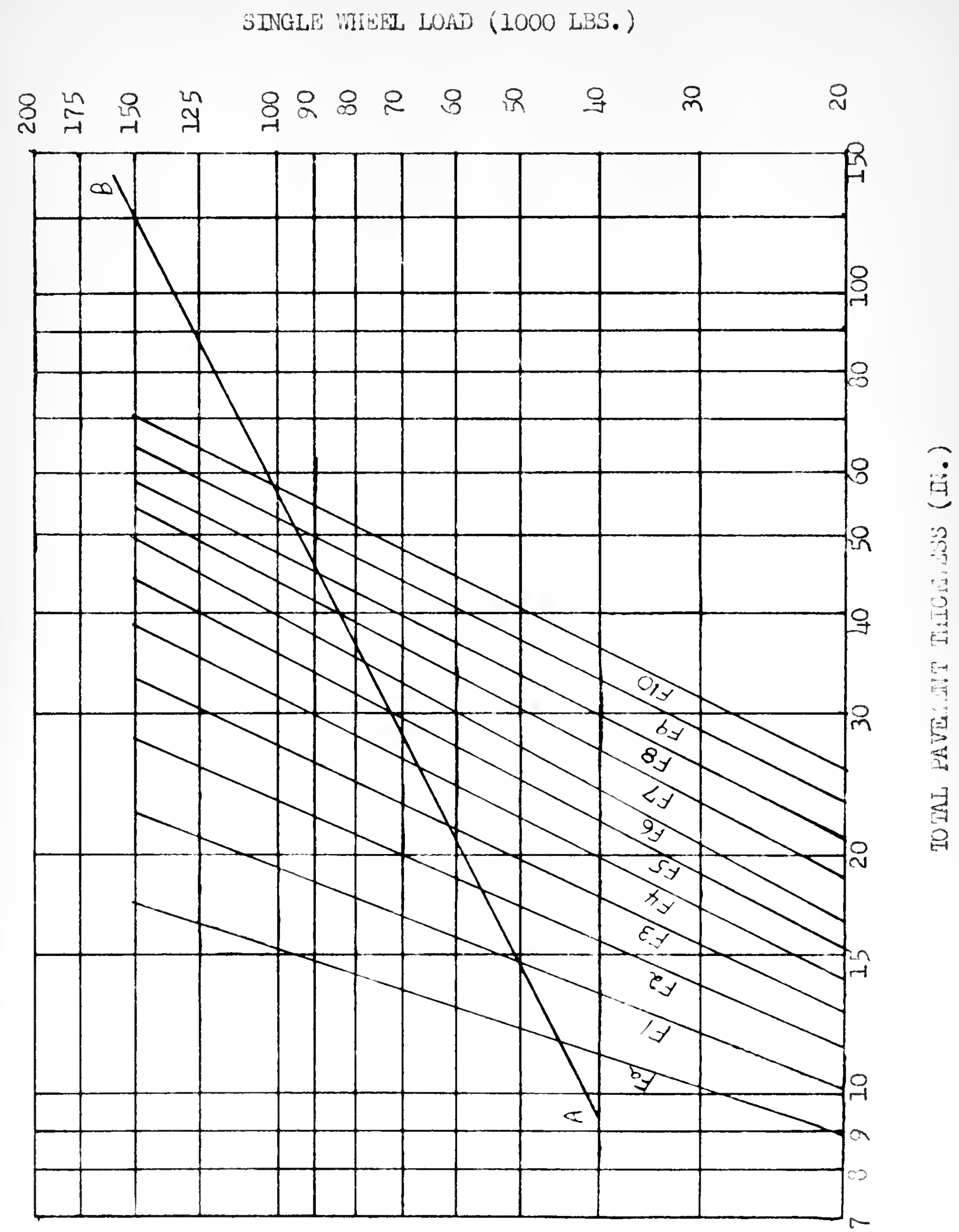
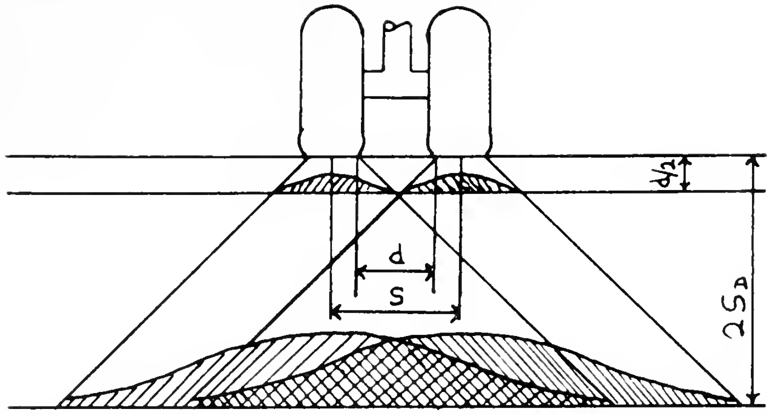
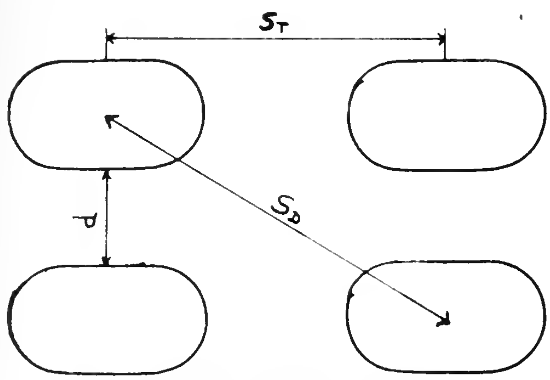


FIGURE 1. SOURCE: REFERENCE 5

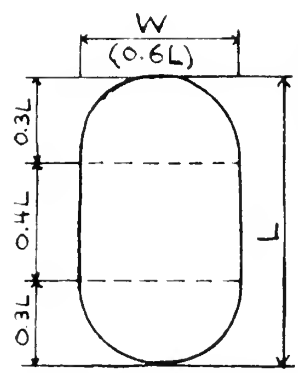
DETERMINATION OF EQUIVALENT SINGLE WHEEL LOADS-FLEXIBLE PAVEMENTS



DISTRIBUTION OF WHEEL LOADS THROUGH FLEXIBLE PAVEMENTS



DUAL TANDEM GEAR TIRE IMPRINT



SINGLE TIRE IMPRINT

FIGURE 2. SOURCE: REFERENCE 5

LOAD DISTRIBUTION AND TIRE IMPRINT DATA